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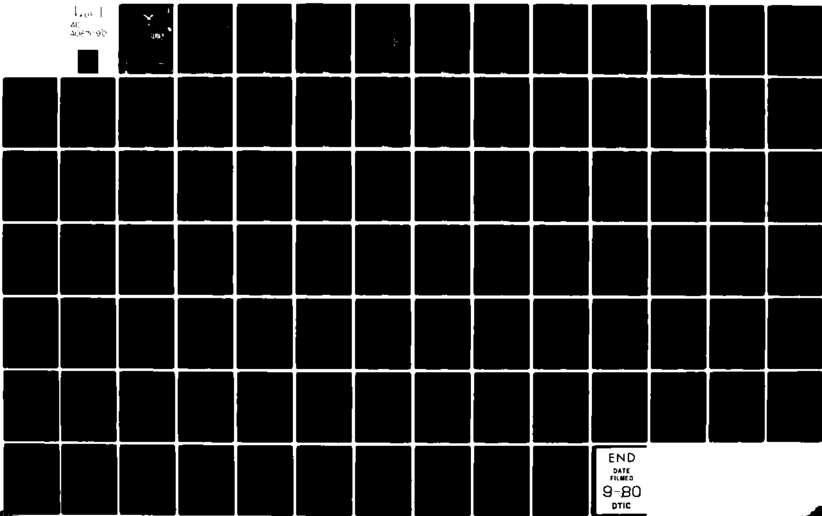

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A CORRELATION BETWEEN THE ASSIGNMENT OF PERSONNEL TO TECHNICAL ORDER VALIDATION/VERIFICATION VERSUS TECHNICAL ORDER DEFICIENCY FORMS GENERATED

Herman Williams, GS-13
Arthur B. Winn, GS-11

LSSR 22-80

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During the acquisition phase of weapon system procurement, the technical manuals are developed along with the design of the weapon system. The process of proofing the manual is called validation/verification. This research investigated the relationship hypothesized to exist between the number of people attending validation/verification and the number of AFTO Form 22 discrepancy forms generated when the weapon system was delivered to the using commands. Although the variables were tested to models of linear, exponential and hyperbolic equations, no significant correlation was found to exist.

LSSR 22-80

A CORRELATION BETWEEN THE ASSIGNMENT OF PERSONNEL TO TECHNICAL ORDER VALIDATION/VERIFICATION VERSUS TECHNICAL ORDER DEFICIENCY FORMS GENERATED

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

By

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This thesis, written by

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and

Mr. Arthur B. Winn

has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN LOGISTICS MANAGEMENT

DATE: 9 June 1980

Ronald G. Blackledge
COMMITTEE CHAIRMAN

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CHAPTER I

INTRODUCTION

Background

Americans have paid many prices to protect their country. Nowhere is this more dramatically shown than in the "U.S. casualties in Major Wars [12:420]." Dangers to the well-being of the country are growing. One notes the continuing Soviet expansion which, from 1940 to 1948, engulfed 91.9 million people in the annexation of neighboring countries to the Soviet Union (12:500). Our country's history is checkered with the attempts of our nation to survive and yet grow against the backdrop of social, political, and economic forces in the world--an argument of guns versus butter. If the awareness of past struggles, particularly the Russian expansion, is not enough to suggest a requirement for increased efforts toward a protection of U.S. National Security, then a turn from the pages of history to the pages of a current newspaper will strengthen the view. Hostages held in Iran and Soviet military intervention in Afghanistan highlight the recent requirement for strengthening the forces that assure our national security.

In the era of competing budget priorities--guns and butter--nowhere is the payback more impressive than in the expenditure of funds to take care of weapons we already have--the idea of maintenance. This thesis focuses on maintenance and the proper development of technical data used in its process.

Security has always depended on weapons. Roman and feudal gladiators fought with the sword but modern-day weapons are more sophisticated. Modern technology has provided such diverse weapons as the M-16 rifle and the F-16 aircraft. Many of the more complex weapons which function in the microsecond world of today's electronics are intricate and require high levels of maintenance precision or recurring malfunctions will occur. If malfunctions are allowed to get out of hand, the "sword" is removed from the hand of the "gladiator" and he has no weapon with which to fight. For example, in order for the B-52 to rendezvous at a given point, an assortment of navigational aids, including navigation radars, radios, doppler radars, astrotrackers and sensitive gyroscopic devices are required to permit the navigator to fly the navigational route and get the aircraft to its destination. Only then can the strike be made. Many other supporting systems, like hydraulics, fuel, and basic flight instrument systems, are also necessary. All these systems must be maintained to a high degree of availability.

While it may be obvious that proper weapon maintenance is necessary, what may not be so obvious is the role that is played by the technical data and, more specifically, the technical order (T.O.). The technical order is where the maintenance procedures are standardized into a body of knowledge. When maintaining complex systems, especially with an increasingly younger and inexperienced work force, standard methods, procedures, and instructions are vital. Conceptually, one can visualize a hierarchy of requirements, starting from the requirement of National Security, to a strong Armed Force, to an effective weapon, to adequate maintenance of that weapon system and, finally, to the requirement for accurate and adequate maintenance procedures supporting that maintenance.

The mandate to acquire an Air Force weapon system falls to Air Force Systems Command (AFSC). This organization is responsible for turning new ideas into hardware, and then developing the hardware into an operational system. While it is true that technical data include much of the written communication required to develop the new system, this thesis is concerned only with the part of technical data developed for operational maintenance. Walton described the broad relationship of technical data to the engineering of new weapon systems as follows:

> Engineering new systems entails the consideration of state-of-the-art developments as well as the known scientific principles. . . . To this end, technical data provide the means of communication needed to develop the new system. With this accomplished the data are then called upon to support the new system

after it has been put in commission (for example, to support operations, maintenance, and logistics) [27:4].

On the one hand, the technical data aiding in engineering development would be the engineering data that describe the weapon system in terms of engineering drawings and specifications; on the other hand, the procedural technical data that is developed from the engineering specification eventually is placed in the hands of maintenance.

Technical manuals embody procedural data. Some meaningful assurance of the accuracy and adequacy of the technical manuals is required. Walton discussed the processes that are established by the Air Force Systems Project Office in AFSC for building and checking these technical manuals. He discussed the planned subprogram for a technical manual system development and activation in terms of a system model document with twelve elements that comprise the many requirements, documents, basic concepts, functional flow diagrams, training equipment listings, and calculations. He continued:

> A validation and verification (V&V) plan is also developed as part of the quality control program to technical manuals. (Validation is a term commonly used to describe the contractor program of proving technical data against operating equipment. Verification is a term used to describe a similar program performed under the cognizance of the customer.) [27:18].

The emphasis placed on this program aspect (V&V) can be seen from two other quotes from Walton:

> Each development program should provide at least a tentative plan for validation, verification, and demonstration of procedural technical data [27:369].

and also:

> When proving out the technical data in a verification program, the critical concerns should be the possible lack of information, and the accuracy of the information that is provided [27:37].

But what if the foregoing critical concerns are not observed? What would be the consequence of little or no V&V of technical manuals?

If the purpose of technical data is communication, it follows that inaccurate technical data results in faulty communication. When this occurs, an Air Force technical manual discrepancy form (AFTO Form 22) is generated by the user (35:6-2). The AFTO Form 22s generated describe the difficulties the user has encountered during his maintenance of the weapon system.

The following case illustrates the effect of inaccurate technical manuals. In the B-52 modification Inspect and Repair As Necessary (IRAN) program at Kelly Air Force Base during the 1960s, it was discovered that the technical manuals were not adequate in checking out the avionic subsystems. Aircraft repair and return schedules had to be slipped since maintenance could not be completed. Management alerted the weapon system designer, Boeing Aircraft, and original contractor engineering data were retrieved to accomplish depot checkout. Upon receipt of these data it was found that the complex procedure of electronically solving the various navigational triangles to ascertain proper heading and drift readouts were imbedded in the test procedure and had to be laboriously recalculated to recreate and determine the technical data errors (13). More precisely, many underlying formulas used longitude and latitude vectors and computed trigonometric values in the solutions of the navigation problems in testing the instruments. It was found that since the geographic location of Wichita, Kansas, differs from that of San Antonio, Texas, those readouts were incorrect. This contributed to many, many maintenance problems until the system discrepancy was discovered. While the AFTO Form 22 process identified the general problem areas as each calculation was flagged as incorrect, it was apparent that a better review of the procedure during technical manual V&V would have eliminated the subsequent AFTO Form 22 concerns. This thesis, then, is focused on the relationship of a program's V&V effort and subsequent AFTO Form 22s. Its purpose, beyond stating the obvious relationship, is to build up the details of the relationship and arrive at some conclusions concerning AF management in this area.

Definitions

Key terms and abbreviations used throughout this paper are summarized as follows:

1. Air Force Technical Order (AFTO) Form 22, Technical Order System Improvement Report--Air Force form used for recommending improvements in formal technical orders (T.O.s) and those preliminary T.O.s authorized for operational and maintenance use.

2. Correlation--the state of relationship such that to each member of one set or series a corresponding member of another set is assigned.

3. Integrated Logistics Support (ILS)--a composite of the elements necessary to assure the effective and economical support of a system or equipment at all levels of maintenance for its programmed life cycle.

4. Integrated Logistics Support Office (ILSO)--refers to that function within the Systems Program Office responsible for ensuring the timely integration of logistics considerations during program acquisition.

5. Maintenance--the upkeep, preservation, and repair of weapon systems, weapon system components, or equipment.

6. Subsystem--the necessary assemblies, subassemblies, and parts connected or associated together to perform one or more specified functions, usually as a major subdivision of a complete operational system.

7. Technical Orders--a group of publications that embody the procedures to operate/maintain Air Force weapon systems, weapon system components, or equipment.

8. Validation--the process by which the contractor tests maintenance and operating procedures in the proposed T.O.s for technical accuracy, adequacy, completeness, and compatibility with the requirement of the applicable military specifications.

9. Verification--the process by which T.O.s are tested and proven (by Air Force personnel under Air Force jurisdiction) to be clear, logical, and adequate for operating and maintaining associated equipment and for certifying that T.O.s are compatible with the pertinent hardware, tools, and support equipment.

Literature Review

The development and acquisition of Air Force weapon systems is the responsibility of the Air Force Systems Command (AFSC). AFSC accomplishes this task through product divisions, one of which is the Aeronautical Systems Division (ASD). The product division directs action of Systems Program Offices (SPOs). The SPO Director, under the single manager concept, is the individual responsible for a total program (5).

The Air Force Logistics Command (AFLC) is the supporting command in the acquisition of weapon systems, and accomplishes its mission through the Air Force Acquisition Logistics Division (AFALD) (4).

The AFALD mission is to ensure logistical supportability early in the acquisition process with a commitment to reducing maintenance problems during the system's life cycle.

To ensure that logistics support design requirements are in conformity with performance design requirements, the Commanders of AFSC and AFLC approved the assignment of AFLC logistics personnel to each SPO for Integrated Logistics Support (ILS) responsibilities (19:3). DOD Directive 4100.35 describes Integrated Logistics Support as:

> . . . a composite of the elements necessary to assure the effective and economical support of system or equipment at all levels of maintenance for its programmed life cycle. It is characterized by the harmony and coherence obtained between each of its elements . . . [36:7].

Air Force Regulation 800-8 identifies "the elements:"

Maintainability and Reliability Interface
Maintenance and Planning
Support Equipment
Supply Support
Packaging, Handling, and Transportation
Technical Data
Facilities
Manpower Requirements and Personnel
Training and Training Support
Logistics Support Resource Funds
Logistics Support Management Information
Computer Resources
Energy Management
Survivability
ILS Test and Evaluation [34:11]

The ILS staff is responsible for each of these elements.

Validation and verification is a subset of the "technical data" element. This study will focus on the element "Technical Data" and particularly the AFALD logistics responsibilities relative to the validation and verification efforts in the technical orders acquisition program. As an initial indicator of the scope of the V&V manning problems, the following example is cited. During the calendar years 1977 and 1978 AFALD submitted additive manpower packages (requests for fifty-nine spaces) through Hq AFLC to the Air Staff in support of unprogrammed workload. Although the additive requirements were recognized, only twenty-six spaces were allocated with the remaining thirty-three spaces to be considered in future manpower outyear programs.[1] This meant the thirty-three spaces had to be filled from current manpower resources. Overall manning of the ILS effort, including the Technical Data element, is significantly below that requested.

Colonel Richard F. Gillis (ASD/AFHL), former A-10 Deputy Program Manager for Logistics, stated that he had to reprocure contractor based technical order data because inadequate technical data were originally purchased. He generalized his comments to state that there is a requirement

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[1]A Point Paper (July 1978) addressing AFLC/CS Letter "Identification of Trade-off Candidates for Manpower Increases," 19 January 1978, and the non-allocation of additive manpower authorization to support new workloads.

for more qualified AFLC logisticians upon the establishment of the SPO cadre (9).

The AFALD FY82-86 Program Objective Memorandum (POM) Input identifies current additive manpower requirements for Technical Order Management during FY81 (Calendar Year 1980), through FY83. It also identifies the impact, if not staffed, as follows:

> The use of matrix assistance, overtime, and part time assistance from other program personnel will not provide a viable substitute for full time dedicated support. If dedicated support is not provided within the stated time frames, . . . the result will be a deteriorating logistics support posture [2:Sec.II, p.0-5-19].

And specifically to the point of this thesis:

> Without the additional manpower spaces, program acquisition support for Technical Orders will continue to be limited to only a small percentage of programs requiring assistance. This in turn will continue to foster the current Air Force T.O. problems which result in fielding T.O.s that are inadequate to support new Air Force systems and that require costly changes [2:Ch.II,p.0-5-27].

The Deputy for Product Evaluation, Engineering and Test (PT) serves as the AFALD corporate memory for lessons learned and operates a repository of technical data and provides feedback to AFLC and AFSC on prior identified design and product deficiencies (4:p.4-1). The following are specific examples of lessons learned on specific problems associated with technical orders at the user organization:

> Field use of inadequately verified technical data causes unnecessary maintenance manhours to research corrections needed; maintenance manhours to develop work around procedures [1:6].

> Unvalidated manuals for the operation and maintenance of equipment undergoing test and evaluation, can result in technicians being unable to perform the task as directed by the manuals [1:7].

> Lack of adequate technical order (T.O.) validation and verification results in inaccurate data and increases maintenance manhours expended in troubleshooting equipment deficiencies [1:10].

> Verification of Technical Orders (T.O.s) requires: (1) scoping the size and effort, (2) identifying and programming for the qualified resources required to support the verification effort [1:18].

One conclusion from the literature review is the inescapable consensus of experts that the field of ILS (including Technical Data) is undermanned. Another conclusion is that the field is gaining more attention, in general, and Technical Data is being looked at, in particular. General William J. Evans, former AFSC Commander, emphasized this thought:

> . . . The recent establishment of a HQ AFSC DCS/Test and Evaluation will focus not only on performance testing, but validation of logistics supportability, compatibility of AGE, and Tech Order validation [18:98].

Statement of the Problem

The continued Department of Defense budgetary constraints and personnel reductions for complex weapon systems have severely impacted both the AFSC and AFLC ability to provide optimal manpower for validation and verification of technical orders. Because of a great lack of trained people and money to hire them, many AF areas are not optimally manned. The chore of good management becomes that of balancing the loading of people such that, even though each area is undermanned, the ultimate product is the best possible for that total amount of resources. The crucial question of this thesis concerns how much good increased manning of verification and validation efforts would do; that is, is the marginal utility of more people, in terms of reducing AFTO Form 22s, high or low?

Research Objective

Many Air Force development programs currently are undermanning their technical order verification and validation effort to the point that they may not be enjoying economic benefit for investment of effort. The marginal utility of adding more people might be quite high.

For the purposes of this study, the number of people assigned to the V&V effort by the ILSO component of an AF System Program Office represents the investment of effort. Decreasing numbers of corresponding technical order discrepancy AFTO Form 22s represent increasing benefit to weapon system maintenance. Increasing numbers of technical order discrepancy AFTO Form 22s represent decreasing benefit to weapon systems maintenance.

This study identifies the relationship that exists between the number of people assigned to the verification and validation effort and the number of AFTO Form 22s generated during a subsequent time period.

Therefore, the research objectives are:

1. To identify the relationship between numbers of people assigned to the validation and verification effort and the numbers of AFTO Form 22s generated.

2. To evaluate this relationship in terms of marginal benefits (decrease in AFTO Form 22s) per increase of people assigned to verification and validation efforts.

Research Hypothesis

The number of people assigned in a program's ILS shop to the validation and verification effort is inversely related to the subsequent number of AFTO Form 22s (Technical Order Discrepancy Reports) generated for that program.

1. The relationship exhibited follows a pattern similar to an exponential curve with a marked characteristic at some point of significantly smaller marginal return (in reduced AFTO Form 22s) relative to the increased manning.

2. There is a significant proportion of programs which fall in the uneconomical area using the marginal analysis in hypothesis 1 (i.e., either grossly too many or too few people).

CHAPTER II

COLLECTION AND ANALYSIS PLAN

The Conceptual Model

Air Force technical manuals exist to aid personnel to operate and maintain Air Force equipment. Those manuals contain procedures of calibrating, operating, repairing, servicing, fabricating, and troubleshooting AF equipment. If these procedures are not reasonably accurate, the AF equipment may not be either properly operated or maintained. When a user senses an error, and after establishing that a problem exists with the technical order, he generates an AFTO Form 22 describing the deficiency.

When an adequate validation and verification is accomplished, errors in the technical manuals are detected and subsequently corrected prior to the delivery of the weapon system to the user. It is the broad premise of the conceptual model that inadequate verification and validation in the Air Force leads to increased AF generation of AFTO Form 22s.

Validation is done by a contractor and can be done in the absence of Air Force personnel. Opportunities exist for the contractor to err in the press of meeting contractual deadlines. The contractor is also the seller and the

Air Force is the buyer. Air Force interests are not fully protected until Air Force representation in the verification process occurs.

Validation and verification are thus the mechanism to ensure that technical publications provide the user with accurate and readily understandable information, and also that requirements are as prescribed in the statement of work. Validation includes checking of operating and maintenance procedures, which in turn include checkout, calibration, alignment, and scheduled removal and replacement instructions and checklists. These procedures are validated by actual performance or simulation. All other data such as schematic diagrams, wiring data contained in maintenance manuals, and descriptive data contained in all types of manuals are checked against current source data (3:p.2-150).

Verification is the process by which technical publications are checked and proven under Air Force jurisdiction (but, with other agencies if needed) to be adequate for operation and maintenance of equipment procured for operational units. The basic guidance for procedures and scope of verification is contained in T.O. 00-5-1, paragraph 3-2. The verification exercise is normally planned and conducted to obtain maximum effectiveness in evaluating systems, equipment, personnel, and manuals. The technical publications presented for verification will be as complete and accurate as possible to allow completion of verification functions in accordance with the sample verification plan (3:p.2-16).

Verification meetings are conducted to discuss and clarify which technical orders or procedural technical publication data elements are to be checked during demonstration by type, method, and policies to be employed, location, and number and skill of personnel needed to participate in the demonstration of technical orders verification.

In addition, the technical order deficiencies are identified and corrected. Agreements should be reached on further actions to resolve any point not understood or any disagreements that cannot be reached at the meeting. Future meetings and verification efforts should be completed in time to permit delivery of technical orders to the user before arrival of the weapon system.

The presence of Air Force people in the verification phase who check the contractor and question him concerning defects will tend to diminish the number of errors remaining in the manual. This study posits that the number of Air Force people attending a V&V is inversely related to the number of AFTO Form 22s generated in a given period. It is seldom practical to checkout or verify all technical order data during demonstration. For example, tear-down instructions for replacement of certain components with low failure rates might be considered unnecessary for demonstration verification. For those components, desk top (hands-off) verification of the technical orders is sufficient. Also, desk top verification is performed when demonstration verification cannot be completed in time to provide fully verified T.O.s with the first delivered operational weapon system. Preliminary T.O.s are then used for safety and minimal essential verification. However, there exists the high probability of omitting precautionary information needed for the protection of personnel and equipment, if these are taken as final products.

The conceptual model, the numbers of Air Force personnel attending a validation and verification versus the number of AFTO Form 22s generated in a subsequent period, is most correct only if AF personnel are in a position to have "hands-on" the equipment used. That is because only the formal "hands-on" meetings indicate an appropriate validation and verification effort, while desk top validations can vary in comprehensiveness to a marked degree. Desk top verification where the equipment is not present, is accordingly not included in this study.

In some cases, the Air Force equipment may be a relatively simple avionics system such as an ultra high frequency (UHF) radio set. In other cases, the equipment may be a more complex terrain avoidance radar set. In still other cases, the equipment may be as complex as the entire weapon system with aircraft structure related manuals.

The Operational Model

Typically, the first time a machine is operated, some malfunctions surface. Remember, however, that all are not due to faulty technical orders. Also, many technical order malfunctions may not be detected immediately since equipment may be new to the AF user. Accordingly, AFTO Form 22s may be sparse in the first months of use. It is reasonable, however, to expect an Air Force activity to question improper operation and narrow the systemic causes down to specific technical data within six months. The period that is studied for AFTO Form 22 accumulation is twelve months starting after weapon delivery to the user.

The Aeronautical Systems Division (ASD) is one of three product divisions of the AFSC. The ASD mission is to plan, program, and manage the acquisition of aeronautical systems, subsystems, and associated equipment. In addition to aircraft, ASD is concerned with systems such as various air launched missiles, drones, and other equipment ranging from jet engines to standard aircraft escape systems.

The other product divisions are the Electronic Systems Division (ESD), Space Division (SD), Ballistic Missile Division (BMD), and Armament Division (AD). ASD is considered as representative of the Divisions and its convenient collocation with the School of Systems and Logistics at Wright-Patterson Air Force Base led to its selection for this thesis.

The validation and verification is accomplished during the full scale development phase of the ASD System Program. The records of the number of people assigned to the specific V&V meetings exist in the ASD office. When the engineering responsibility is transferred to the system manager at the Air Logistics Center, however, the responsibility for the technical data is also transferred. AFTO Form 22 information therefore cannot come from ASD. Technical data branches at the Air Logistics Centers assume the responsibility of receipt of any discrepancies in the technical manual. AFTO Form 22s that are generated are recorded and processed by these technical data branches. The record and outcome of the AFTO Form 22s are subsequently stored in each ALC computer.

Data Collection

This study will initially select the data concerning AFTO Form 22 numbers generated from ALC computer tapes for selected weapon systems. Each weapon system technical manual is categorized by technical order number. That number, obtained from the Air Force when the manual is first conceived, serves as an identifier for that weapon system's specific manual. No two manuals bear the same number. The technical order number is also referenced when the records of the System Program Office identify the validation and verification events. Thus the two variables, numbers of people assigned to the V&V (of a given technical order by number) and numbers of AFTO Form 22s generated (of a given technical order number) will be used in this study.

Since System Program Offices differ as to the number of T.O.s they generate, it is necessary to standardize the number of people assigned to V&V by counting them in relation to number of T.O.s they must verify. It is only reasonable to assume that for any given V&V meeting, two people assigned to do fifteen T.O.s will do a more comprehensive job than two people doing one hundred T.O.s. While it is recognized that one merely needs to extend the second meeting longer to get the same manhours per T.O., it is rare that V&V meetings actually correspond in length to number of T.O.s. While this situation makes the relationship between V&V and AFTO Form 22s less than precise, it is believed that some standardization is required to give valid results and that this method of standardization yields the essence of the relationship. It should be noted that output is measured in terms of AFTO Form 22s per T.O. This situation already defines a kind of standardization among programs, hence further change is not required.

This process will give conformity among the SPOs and provide a more accurate measuring technique for determining correlation between V&V efforts and AFTO Forms 22.

Thirty programs will be selected and a random sample of technical orders, validation and verification, and subsequent AFTO Form 22s applied to those programs will be studied. The sample size selected was by the heuristic (rule of thumb) approach that a sample size $N \geq 30$ constitutes a minimumly large sample size (12:188). Of the thirty programs, a minimum of ten and a maximum of one hundred samples of technical orders will be selected. This leads to a sample size larger than three hundred and estimated to be about eight hundred. Since it is not uncommon to have over two hundred manuals in a larger weapon system, and as few as twenty in a smaller one, this range seems appropriate. The sampling rule of thumb will be to randomly take 50 percent of each program. This large sample of data comparisons should preclude any generalized concerns of statistical significance. Since it is possible for any one program director to directly influence the size of his V&V effort, he can bias all T.O.s sampled from his program. It is for this reason that the minimum sample size rationale is used on programs instead of total number of T.O.s across programs. The thirty programs will be selected to demonstrate a range of sizes with approximately 50 percent being complete major weapon systems (such as the F-15) and 50 percent being smaller systems (like the Precision Location Strike System). A check will be made during the analysis to see if there is any major difference in the scatter of the two types of data.

The list of attendees who attended validation and verification meetings will be acquired from the system program office having the responsibility of the respective weapon system. If no attendance occurred, then that AFTO Form 22 data will be reported and flagged. This will give a zero abscissa for a positive (AFTO Form 22) ordinate. The AFTO Form 22s will be obtained from the Air Logistics Center having responsibility over the technical data for the respective weapon. Attendees at V&V for each technical order will be plotted against cumulative AFTO Form 22s for each technical order.

Data Analysis

In cases where two variables are functionally related, but the relationship is not known, the relationship is hypothesized by the use of a mathematical expression describing a suspected relationship. The technique of regression and correlation can be used to fit collected data points to a preselected equation form. For example, of a sample of N runs of a process obtained from some source data reveals a content $x_1, x_2, \ldots, x_n$ with corresponding yields $y_1, y_2, \ldots, y_n$ such that there exist data plots (x_1,y_1), $(x_2,y_2),\ldots,(x_n,y_n)$ then the resulting plotting or diagram is called a scatter diagram. It is often possible to visualize a smooth curve approximating that data.

In Figure 1, the data visually appear to fit an imaginary line described by the mathematical expression $y=a_o+a_1X$. For a given unit change of X there is a corresponding and linear change of Y. The slope is constant.

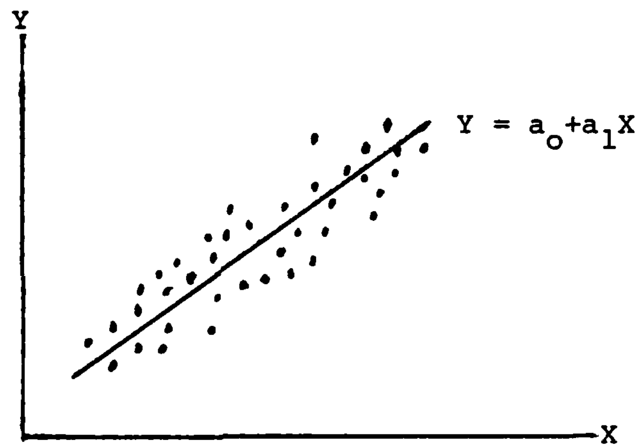


Fig. 1. Approximating Curve

A different relationship exists between the variables in this study. It is the hypothesis that the relationship is nonlinear; for an increase in numbers of people assigned to validation/verification efforts, there is a decrease in the number of AFTO Form 22s generated and the slope of the curve of the function between these two variables is not constant.

In the case of the relationship of the variables in this thesis, one can also conceptually visualize the smooth curve approximating the data. The general problem of finding equations of approximating curves which fit given sets of data is called curve fitting. The model that is hypothesized in this study is an exponential relationship that is inverse as visually depicted in Figure 2. Its general equation is $Y = ab^{X}$.

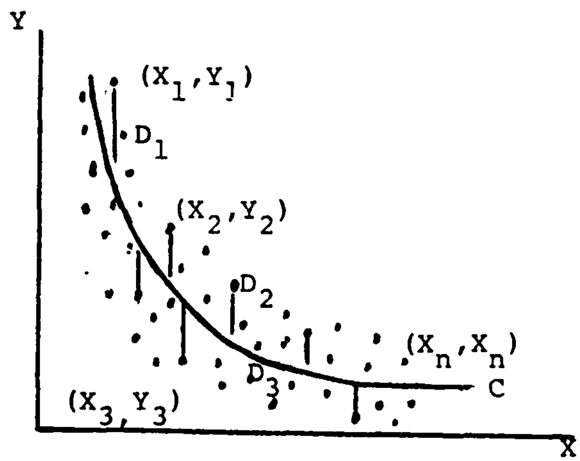


Fig. 2. Best Fit Curve

This version of the approximating curve (c) is: $Y = ab^{-X}$, indicating a negative slope. Associated with each set of data points (X, Y) in Figure 2 is a distance to the curve (C) from Y that can be called D such that for $Y_1, Y_2, \ldots,$ Y_n there exist $D_1, D_2, \ldots, D_n$. This difference is sometimes called a deviation, error, or residual and may be positive, negative, or zero. A measure of the goodness of fit of the curve (C) to the set of data is provided by the quantity $D_1^2+D_2^2 +\ldots + D_n^2$. If this quantity is small, then the deviation or error approaches zero and it can be said that where $Q = D_1^2+D_2^2 +\ldots + D_n^2$ is a minimum, then the approximating curve is the best fitting curve. Specifically, when $Y = a_1+a_oX$, $Q = (a_o+a_1X_1-Y_1)^2 +$ $(a_o+a_1X_2-Y_2)^2 +\ldots + (z_o+a_1\ XN-YN)^2$. Entry of the data points into the computer that transforms the exponential relationship, $Y = ab^{-X}$, to a linear relationship, $Y = a_1+a_oX$, allows the computer to establish the best fit through solutions of the following simultaneous equations called the normal equations for the least squares line:

$$\Sigma Y = a_oN+a_1\Sigma X$$

$$\Sigma YX = a_o\Sigma X+a_1\Sigma X^2$$

The constants a_1 and a_o can be found from the formulas thus derived:

$$a_o = \frac{(\Sigma Y)\ (\Sigma X^2) - (\Sigma X)\ (\Sigma XY)}{N\Sigma X^2 - (\Sigma X)^2}$$

$$a_1 = \frac{N\Sigma XY - (\Sigma X)\ (\Sigma Y)}{N\Sigma X^2 - (\Sigma X)^2}$$

Thus the computations shown explain the computer approach to the fit of a line through the use of data points of a straight line. The remaining transformation from an exponential function to a straight line is shown:

1. $Y = ab^{-X}$

2. $\text{Log } Y = \log a + (\log b)X$

3. $\text{Log } Y = a_o + a_1 X.$

Such that Log Y vs X shows the linear relationship a_o+a_1X. Thus, after transforming the exponential function to a linear function, the computation for a curve fit through the normal equations for the least squares line is accomplished within the computer.

The technique of fitting a set of data points to a chosen curve according to the least squares criterion for best fit is called regression analysis. The use of the preceding methods are parametric and the assumptions in this study are:

1. The data are at least an interval scale (in fact, the data are ratio).

2. The variables are from a normally distributed population.

Under these assumptions the correlation measure used is the Pearson product moment coefficient r. It is a characteristic of r that r^2 is an estimate of the explained deviation of individual data items Y from the mean of Y. In other words, r^2 = the explained variation ÷ the total variation. The higher the ratio of explained deviation to total deviation, the higher the degree of correlation that exists between the variables.

The F-test signifies the degree of confidence one has concerning the R^2 figure derived between the dependent variable and independent variable(s). In this research, F-tests will be run on a probability of .1 to insure that the R^2 confidently models the data.

The R^2 figure and F-test are both instrumental in showing how well a curve fits the data. Assuming a good fit, the curve becomes the informational model on which the next step is based. It is now necessary to determine the point where the scope changes most rapidly. This can be accomplished by finding the point between the limits where slope (b) equals 0 (X axis) and b equals infinity (where the constant equals infinity) on the Y axis. Mathematically this can be shown to be the point where b equals -1. The actual economical range used will be a rectangle defined by 20 percent of the highest number of people doing V&V in the Y axis and 20 percent of the highest measured number of AFTO Form 22s in the X axis. The rectangle will be on the Point of Origin where Y axis intersects X axis. See Figure 3. Comment will be made in the analysis as to the sensitivity of defining the economical rectangle sides of 20 percent of their maximum respective values as opposed to slightly higher values.

Finally, the sample data will be again superimposed over the curve. Each data point will be noted as to its relative position in or out of the economical range. The

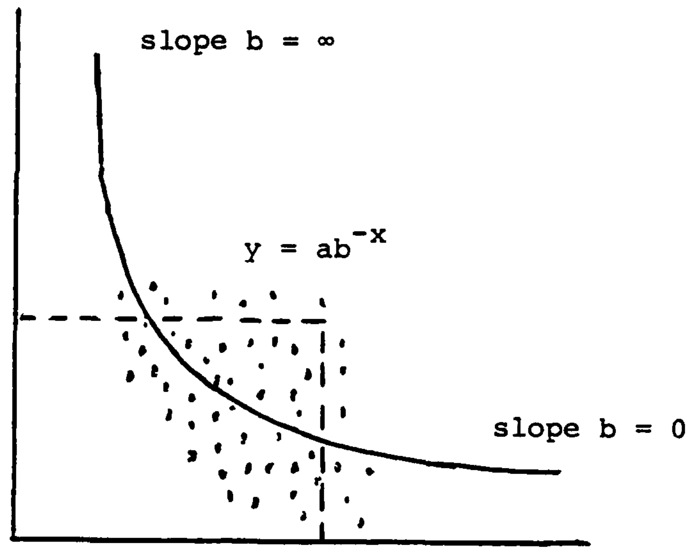


Fig. 3. Economical Area

data will also be evaluated for differences between large and small programs as well as for the possible existence of other distinct distributions inside the overall population distribution.

CHAPTER III

DATA DEVELOPMENT

General

The collection and arrangement of research data necessitated the design of collection forms, a subdivision of the data into small and large weapon systems programs, and the determination of the computer approach that develops the data for analysis. Each of these requirements was met and is discussed in the following sections.

Collection Form

Design

A collection form entitled "T.O. Data Collection Checklist" was designed for identification and control of each technical order number relating to a specific weapon system (see Figure 4). The form design permitted the T.O. data to be identified at both system and subsystem indenture.

The form also identified the research data as to the number of Air Force personnel that participated in the T.O. verification and the number of AFTO Form 22s (T.O. discrepancies) that were generated. The form design linked together three pieces of research data, T.O.s, number of

WPN SYS:	PERSON TO CONTACT:		DATE:				
			OFC SYMBOL:				
		PHONE:	PROG SIZE	NO OF PEOPLE	TO	VV/TO	AFTO 22s
	12						
	12						
	21						
	22						
	31						
	32						
	41						
	42						
	51						
	52						
	11						
	12						
	21						
	22						
	31						
	32						
	41						
	42						
	51						
	52						
	11						
	12						
	21						
	22						
	31						
	32						
	41						
	42						
	51						
	52						

SOURCE: ______________________________ WS S

____

Fig. 4. T.O. Data Collection Checklist

people at verification, and number of AFTO Form 22s generated.

The form also permitted an adjustment to standardize the number of people assigned to T.O. verification relative to the number of T.O.s they must verify.

Format

The heading of the form identifies the weapon system, and the source for the research data. This includes the name of the person contacted, the office symbol, telephone number, and the date of the personal telephone interview. It also identifies in columnar form a listing of each T.O., according to program size, number of people assigned verification, number of T.O.s verified, adjustment for VV/T.O., and the number of AFTO Form 22s generated.
The research data was divided into large and small, as identified in Appendix A.

Program Selection Process

Mr. John Glaser, System Control Officer, Headquarters Air Force Logistics Command, Bomber, Cargo Aircraft and Missile Division (LOAC) provided a listing of fifty (50) aircraft that are currently in the Air Force inventory. This listing was used to contact the system managers for the various systems to garner the data for this study. Contact with the system managers for some of the older aircraft systems revealed that relevant research data was not available; it had either been destroyed during Program Management Responsibility Transfer (PMRT), retired or lost. These programs obviously had to be dropped.

This was also true with some of the older systems for which ASD still had residual management responsibilities. The newer systems, i.e., EF-111 Aircraft, Precision Locator Strike System (PLSS), etc., had not progressed to the Technical Order verification stage; therefore, they too were excluded. In order to obtain a representative sample for this study, therefore, the population was expanded to include weapon systems from two other Air Force Systems Command, Product Divisions, Electronic Systems Division (ESD) and the Space Division (SD). The population sample size included large and small programs as follows:

1. C-5
2. A-10
3. F-15
4. F-16
5. C-141
6. F-5E
7. F-4E
8. E-4A
9. MINUTEMAN III

*10. TRACAL (Instrument Landing System)

*11. GATES (Solar Observing Optical Network)

*12. UH-1 (Helicopter)

*13. AFSATCOM (Satellite Communication)

*14. 427M (Satellite Tracking & Warning System)

*15. DSP (Defense Support Program)

*16. AGM65E

*17. BISS (Environment Surveillance System)

*18. PAVE PENNY (Laser Receiver)

*19. PAVE SPIKE (Laser Designator & Ranger)

*20. AAD-5/ASQ 154 (Infra Ray Camera)

*Denotes small systems.

Both the F-15 and F-16 aircraft were deleted from the study because the data obtained was not according to the study criteria. Study criteria required formal verification of T.O.s to be completed and in the hands of the user for at least one year subsequent to verification of the T.O. Technical order verification was not accomplished prior to delivery of the aircraft to the user for these programs. This reduced the sample size to eighteen programs, which formed the research data base.

Approach to Computer Programs

The research data was fed into two computer programs to determine the relationship between the variables stated in the hypothesis. One of the programs is called CURFIT and details of that program can be found in the CREATE shop at HQ AFLC/ACTAS. The second computer program is more widely known and is called the Statistical Package for the Social Sciences (SPSS).

The CURFIT computer program is designed to test the research data against six frequently used equation forms. The computer program yields either the index of determination, which is another name for the coefficient of determination, or the words "CAN'T FIT" under the heading of the index of determination. The equation forms matched were:

(1) $Y=A+BX$

(2) $Y=Ae^{BX}$

(3) $Y=A \cdot X^{B}$

(4) $Y=A+(B/X)$

(5) $Y=1/A+B^{X}$

(6) $Y=X/A+B^{X}$

CHAPTER IV

ANALYSIS

This chapter addresses three approaches to analysis of the research data. The first approach uses a computer program written in BASIC computer language and will be discussed from the standpoint of regression analysis as it applies to six approximating curves provided by the CURFIT analysis. The second and third approach uses a computer program written in CARDIN and will be discussed from the standpoint of a scattergram as it applies to a linear approximating curve called SPSS analysis. Additionally, the third approach includes the research technique of transforming the research raw data in order to determine the goodness of fit to an exponential equation similar to the equation of the form $y=ab^{-x}$ discussed in Chapter II. The values of the coefficients of determination can be exhibited in all three approaches to determine the goodness of fit to the equation under study.

Recalling that the equations represent a prospective information model if a high degree of correlation exists, the research focused on the degree of correlation exhibited by each computer result.

CURFIT Analysis

The total research data of 164 data pair were fed into the CURFIT program and can be seen on data lines 100 through 210 in the CURFIT program shown in Appendix B. When the program was run the computer results revealed no fit at all for the following approximating equations:

(2) $Y=Ae^{BX}$

(3) $Y=A \cdot X^{B}$

(5) $Y=1/A+B^{X}$

(6) $Y=X/A+B^{X}$

Although the computer results showed some correlation existed for two of the six equations that the research data was measured against, the correlation was slight. The correlation for the remaining two equations was:

Curve Type	Index of Determination	A	B
(1) Y=A+BX	.1000884	3.255	2.4657
(4) Y=A+(B/X)	.0856706	13.500	-6.007

Values shown under variables A and B in the chart establish the most applicable fitted line for the equation exhibited. Since the index of determination represents the ratio of explained deviation to total deviation discussed earlier, it may be noted that only 8 to 10 percent of the deviation in the field of the sample data is explained.

SPSS Analysis

In the second approach to the analysis of the combined large and small weapon system data, the research data was used to build a computer file system called COMP. This file then was input to a program of cards that are computer routines within themselves. It is called the CARDIN system (as opposed to the BASIC system) and the sequence of computer operations were individualized for a given research. The computer cards were aggregated and that set of cards became identified as a group. The variables were given names and the program was run.

This program was called COMPOSITE. The SPSS program cards labeled scattergram and statistics, yielded scatterplots and statistical results respectively. The variable name for the data on the number of people attending validation/verification was NVVER (VVER), and the variable name for the data on the number of AFTO Form 22s generated was NAFTOS (AFTOS).[2] Thus, the research to determine whether or not a significant relationship existed between the variables NVVER and NAFTOS was facilitated by the execution of the scattergram and statistics card computer routine. The visual perception of the scattergram plot revealed no significant relationship between the variables stated in the research. No trend in data cluster could be identified and

[2] The variables NVVER and VVER; and NAFTOS and AFTOS are used interchangeably in this thesis.

the low values computed in the statistic card results supported by the impression generated by scattergram observations. For example, the R^2 value, coefficient of correlation, was 0.0903. The composite correlation, Table 1, illustrates the statistics card outputs.

TABLE 1

COMPOSITE CORRELATION

RUN NAME: COMPOSITE

FILE NAME: COMP

Correlation	Std Err of Est	Plotted Values	Excluded
R 0.300	12.035	164	0
R^2 0.0903			

The research was continued to investigate whether or not a single weapon system program or group of weapon systems program data was reducing the correlation values. A subfile structure of the data was established and subfile identification was designed into the existing computer card set. Large weapon systems and small weapon systems previously identified on the T.O. Data Collection Checklist were identified using file structure methods in SPSS. The results of this approach are summarized in the Small Systems and Large Systems Charts (Tables 2 and 3).

TABLE 2

SMALL SYSTEMS

RUN NAME: SMALSUB

FILE NAME: SMASYS

Subfile	Correlation R	Correlation R^2	Std Err	Plotted	Excluded
TRAC	-0.59	0.351	0.832	5	0
AADS	-0.73	0.529	6	4	0
427M	0.081	0.006	4.27	24	0

TABLE 3

LARGE SYSTEMS

RUN NAME: LARGSUB

FILE NAME: LARSYS

Subfile	Correlation R	Correlation R^2	Std Err	Plotted	Excluded
C-5	-0.18	0.032	10.13	22	0
A-10	0.54	0.295	8.39	15	0
C-141	-0.50	0.253	5.35	10	0
F-5	+0.09	0.009	8.00	7	0
MN3	-0.23	0.054	20.78	9	0

The small and large subfiles not shown were run by the computer but there was not enough relation between the variables of those subfiles for the computer to exhibit a coefficient of correlation. It should be noted that the coefficient of determination, R^2, ranged from 0.006 to 0.53. In cases where the coefficient was 0.35 or more, the number of plotted values was 5 or below. Conclusions concerning these points will be discussed in the next chapter.

SPSS Analysis with Transformed Data

In the previous programs, the exponential equation was $Y=Ae^{BX}$. The equation $Y=ab^X$ was not addressed by those programs. In order to evaluate a goodness of fit of equations in the family of $Y=AB^X$ in a linear regression program, it is required that the common logarithm of Y be taken and the regression analysis of the log Y vs X be accomplished to ascertain whether correlation to the information model $Y=ab^X$ will test for $Y=ab^{-X}$.

The following relationships were established with SPSS compute cards:

	Variable Name	Variable	
(1)	NVVER	X	
(2)	NAFTOS	Y	
(3)	PNVVER	(X+1)	NVVER+1
(4)	PNAFTOS	(Y+1)	NAFTOS+1
(5)	MNVVER	(-1)(X+1)	

(6) PLVVER log (X+1)

(7) PLAFTOS log (Y+1)

On (3) through (7) the number 1 is included since the raw data (X, Y) or (NVVER, NAFTOS) contained zeros and computing the logarithm of zero is mathematically meaningless.

The final SPSS program (see Figure 5) reveals the development of the variable MNVVER or minus X. For ease of interpretation the following definitions for the code names apply:

NVVER. The code name that is the X variable of raw data. The number of people to attend validation/verification.

NAFTOS. The code name that is the Y variable of raw data. The number of AFTO Form 22s generated.

PNVVER. The code name that describes the X variable data manipulated by the addition of one in order to effect the logarithm of the number.

PNAFTOS. The code name that describes the Y variable data manipulated by the addition of one in order to effect the logarithm of the number.

PLVVER. The code name that describes the logarithm of the X variable data manipulated by the addition of the number 1.

PLAFTOS. The code name that describes the logarithm of the Y variable data manipulated by the addition of the number 1.

```
PRINT LOGCOP2

05/16/80    19.06

$      IDENT   WP1186,AFIT-LSG, WILL WINN CL80 SEC 2
$      SELECT  SPSS/SPSS
RUN NAME       COMPOSITE WITH Y=AB**-X
LIST ERRORS
FILE NAME      LOG COP2
VARIABLE LIST  NVVER,NAFTOS
INPUT MEDIUM   CARD
N OF CASES     164
INPUT FORMAT   FREEFIELD
COMPUTE        PNVVER=NVVER+1
COMPUTE        PNAFTOS=NAFTOS+1
COMPUTE        PLVVER=LG10(PNVVER)
COMPUTE        PLAFTOS=LG10(PNAFTOS)
COMPUTE        MNVVER=(-1)*PNVVER
VAR LABELS     NVVER,NO OF PEOPLE TO VALVER/NAFTOS,NO OF AFTOS
VAR LABELS     PLVVER,LOG OF NO OF PEOPLE TO VALVER/PLAFTOS,LOG OF NO AFTOS
LIST CASES     CASES=164/VARIABLES=MNVVER,PLAFTOS,NVVER,NAFTOS
CONDESCRIPTIVE PLVVER,PLAFTOS
READ INPUT DATA
$      SELECTA 80A011/COMP,R
SCATTERGRAM    PLAFTOS(0,3) WITH MNVVER (LOWEST,HIGHEST)
OPTIONS        6,7
STATISTICS     ALL
REGRESSION     VARIABLES=PLAFTOS,MNVVER/REGRESS   =PLAFTOS WITH MNVVER/
FINISH
$      END JOB

*
```

Fig. 5. Computer Run for Exponential Equation

It can be seen that the transformed variable, PLAFTOS and MNVVER are required as inputs log Y and -X to effect the transformation from:

$$Y=ab^{-X} \text{ (the exponential equation)}$$

to

$$\log Y=\log a+(-X)(\log b).$$

Thus, the exponential equation is transformed into a linear equation and the techniques of regression analysis apply.

The computer run with the aforementioned variables showed little correlation between the 164 data pair (-X, log Y). The values are shown in Table 4.

TABLE 4

EXPONENTIAL EQUATION RESULTS

RUN NAME: COMPOSITE WITH Y=AB**-X

FILE NAME: LOG COP 2

Correlation				
R	R^2	Std Err	Plotted Values	Excluded
-0.197	0.039	0.5035	164	0

The same technique (see Figure 6) used to develop the transformed variables for $Y=ab^{-X}$ was used to input the log Y vs log X to determine if a relationship existed for the geometric curve:

$$Y=aX^{b} \text{ (the geometric equation)}$$

```
PRII@NT LOGCOP

05/16/80    19.04

$       IDENT   WP1186,AFIT-LSG, WILL WINN CL80 SEC 2
$       SELECT  SPSS/SPSS
RUN NAME        COMPOSITE
FILE NAME       LOG COP
VARIABLE LIST   NVVER,NAFTOS
INPUT MEDIUM    CARD
N OF CASES      164
INPUT FORMAT    FREEFIELD
COMPUTE         PNVVER=NVVER+1
COMPUTE         PNAFTOS=NAFTOS+1
COMPUTE         PLVVER=LG10(PNVVER)
COMPUTE         PLAFTOS=LG10(PNAFTOS)
VAR LABELS      NVVER,NO OF PEOPLE TO VALVER/NAFTOS,NO OF AFTOS
VAR LABELS      PLVVER,LOG OF NO OF PEOPLE TO VALVER/PLAFTOS,LOG OF NO AFTOS
LIST CASES      CASES=164/VARIABLES=PLVVER,PLAFTOS
CONDESCRIPTIVE  PLVVER,PLAFTOS
READ INPUT DATA
$       SELECTA 80A011/COMP,R
SCATTERGRAM     PLAFTOS(0,2.1) WITH PLVVER(0,2)
OPTIONS         6,7
STATISTICS      ALL
REGRESSION      VARIABLES=PLAFTOS,PLVVER/REGRESSION=PLAFTOS WITH PLVVER/
FINISH
$       END JOB

*
```

Fig. 6. Computer Run for Geometric Equation

The results of this run are shown in Table 5. In both cases, exponential and geometric, no significant relationship could be determined by either examination of the scatterplots for the A-10, C-5, 427M systems and the composite program or their correlation coefficients.

TABLE 5

GEOMETRIC EQUATION RESULTS

RUN NAME: COMPOSITE

FILE NAME: LOG COP 2

Correlation R	R^2	Std Err	Plotted Values	Exclude
0.249	0.0624	0.4973	164	0

CHAPTER V

FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

Assumptions and Findings

The assumptions that were made prior to the research were that if people were sent to the validation/verification and conducted the actual checkout of the technical manual in question, it would have an effect to minimize the eventual generation of technical order discrepancy forms called AFTO Form 22s. It was also an assumption that if smaller or greater numbers of people were sent to the validation/verification for the purpose of the actual technical manual checkout, then some measurable change in the amount of discrepancy Form 22s would occur. The research failed to support a relationship between the research variables.

The findings exhibited coefficients of determination well below 35 percent as a general rule and in the one case where the coefficient was at slightly above 50 percent, the number of cases was extremely small. Examination of the values for the error sum of squares (SSE), regression sum of squares (SSR) and the total sum of squares (SSTO), supported the view that little or no relationship existed between the variables for a given equation. A typical example is found in the regression analysis portion of the computer run that tested the research data for fit to the equation $Y=ab^{-X}$ (see Table 6).

TABLE 6

REGRESSION ANALYSIS RESULTS

Source of Variation	Sum of Squares	Mean Square
Regression	1.66736	1.66736
Residual (Error)	41.07247	0.25353

Recalling the total variation (SSTO) is found by adding SSE and SSR then 1.66736 plus 41.07247 equals 42.73983. It can be seen that the contribution of the explained variation, 1.66736, to the total variation 42,73983, is small. That rate is seen as the value R^2. In general, it can be stated that the closer the explained deviation equals the total deviation, the closer the value of R^2 approaches one. In this case, a value of R^2 that equals 0.039 indicates only 3 hundredths of the total deviation can be explained.

Hence the conclusion of this research is that little correlation of the research variables exists for the model $Y=ab^{-X}$ or any of the models tested. There was no indication to suspect broader coverage of weapon systems would yield better correlation, but since records were destroyed or lost as in the case of the older weapon systems such as the F-100, research is limited.

Although time and resources are expended in the sending of verification teams to validation and verification sites, the researchers could find no previous study establishing an empirical base. This is not to say that verification should not be done, but since scarce resources are involved, it seems reasonable that further study concerning the cost-benefits realized are required when verification involves more than one person.

Conclusions

Since no significant correlation could be established between the research variables, it must be concluded that some other major factors determine the number of AFTO 22s a program ultimately sees. Within the range of people assigned to validation and verification on the studied systems, the conclusion must be that manning was not a factor. This is an interesting conclusion in that it is counter-intuitive and certainly not an argument for increased validation and verification manning as some would wish.

Recommendations

In view of the research conclusions, an expansion of or continuation of this study is not recommended. However, further study should look at other external environmental factors to determine if potential correlations exist relative to technical data verification. In line with this study, it is recommended that close scrutiny be paid to the data collection and analysis to verify if indeed the study is valid. We think it is. If this is true, program offices should be advised that, within limits of the data range of validation and verification manning seen in this study, AFTO 22s are not sensitive to undermanning in prior validation and verification.

APPENDICES

APPENDIX A

T.O. DATA COLLECTION CHECKLIST

WEAPON SYSTEM: C-5

(SOURCE: 28)

CONTROL NUMBER	TECHNICAL ORDER	NO. PEOPLE VV	NO. OF T.O.s	VV/T.O.	AFTO 22s
00101	12P5-4-40-2	3	2	1.52	15
00102	12P5-4-49-4	3	2	1.52	21
00103	12P5-4-50-4	3	1	3	9
00104	12P5-4-52-4	3	1	3	6
00105	12P5-4-55-3	3	1	.75	21
00106	12P5-4-56-2	3	1	3	0
00107	12P5-4-63-3	3	2	1.52	6
00108	12P5-4-63-4	3	2	1.52	9
00109	12P5-4-66-3	2	3	.66	0
00110	12P5-4-64-4	2	3	.66	0
00111	12P5-4-66-4	2	3	.66	0
00112	12P5-4-67-3	3	1	3	0
00113	12P5-4-67-8-2	3	1	3	15
00114	12P5-4-67-8-3	3	1	3	15
00115	12P5-4-67-8-4	3	1	3	6
00116	12P5-4-67-23	3	4	.75	36
00117	12P5-4-67-33	3	4	.75	21
00118	12P5-4-67-33-1	3	4	.75	0
00119	12P5-4-67-33-2	3	4	.75	0
00120	12P5-4-67-43	3	3	1	24
00121	12P5-4-67-63	3	3	1	12
00122	12P5-4-67-83	3	3	1	18

WEAPON SYSTEM: A-10

(SOURCE: 26)

CONTROL NUMBER	TECHNICAL ORDER	NO. PEOPLE VV	NO. OF T.O.s	VV/T.O.	AFTO 22s
00201	1A-10A-33-1-1	9	4	2.27	1
00202	1A-10A-33-1-2	9	4	2.27	22
00203	35C1-4-79-1	2	3	.66	0
00204	35C1-4-80-1	2	3	.66	0
00205	4SA2-53-3	2	3	.66	0
00206	5A11-7-11-3	2	1	2	0
00207	4S1-99-3	2	1	2	12
00208	4S1-100-3	2	1	2	11
00209	4S10100-3	2	1	2	1
00210	5A13-5-17-3	2	1	2	1
00211	43E24-6-4-1-1	7	3	.704	10
00212	43E24-6-4-1-2	7	3	.704	4
00213	43E24-6-4-1-3	7	3	.704	24
00214	13A5-46-3	7	1	7.1	28
00215	13A5-46-4	2	1	2	7

WEAPON SYSTEM: C-141

(SOURCE: 19)

00501	5N5-16-2-2	9	1	9	0
00502	5N6-9-5-2	8	3	2.66	0
00503	12P5-4-44-2	8	3	2.66	0
00504	12P5-4-44-3	8	3	2.66	2

CONTROL NUMBER	TECHNICAL ORDER	NO. PEOPLE VV	NO. OF T.O.s	VV/T.O.	AFTO 22s
00505	5N5-7-3-8-1	6	6	1	12
00506	5N5-17-2-8-1	6	6	1	13
00507	5A7-5-2-8-1	6	6	1	4
00508	5A43-2-3	6	6	1	15
00509	33DA9-30-1	6	6	1	5
00510	33DA11-79-1	6	6	1	2

WEAPON SYSTEM: F-5E

(SOURCE: 7)

CONTROL NUMBER	TECHNICAL ORDER	NO. PEOPLE VV	NO. OF T.O.s	VV/T.O.	AFTO 22s
00601	33DA116-6-1	5	3	1.66	2
00602	33DA116-7-1	5	3	1.66	1
00603	11F23-4-2-2	5	3	1.66	20
00604	12R2-2ARC164-3-1	3	1	3	0
00605	11F1-APQ159-2	4	5	.8	1
00606	11F1-APQ159-12	4	5	.8	0
00607	11F1-APQ159-22	4	5	.8	0

WEAPON SYSTEM: F-4

(SOURCE: 13)

CONTROL NUMBER	TECHNICAL ORDER	NO. PEOPLE VV	NO. OF T.O.s	VV/T.O.	AFTO 22s
00701	1F4E-2-19	10	11	.91	42
00702	1F4C-6	10	11	.91	13
00703	1F4C-6WC-4	10	11	.91	1
00704	1F4C-6WC-7	10	11	.91	1
00705	1F4C-6WC-3	10	11	.91	4
00706	1F4G-2-19-1	10	11	.91	2
00707	1F4G-2-33	10	11	.91	1

CONTROL NUMBER	TECHNICAL ORDER	NO. PEOPLE VV	NO. OF T.O.s	VV/T.O.	AFTO 22s
00708	1F4E-2-11	10	11	.91	1
00709	1F4E-2-12	10	11	.91	6
00710	1F4E-2-13	10	11	.91	3
00711	1F4E-2-33	10	11	.91	1
		WEAPON SYSTEM: E-4A			
		(SOURCE: 23)			
00801	1E-4A-2-27	7	10	.70	3
00802	1E-4A-2-25	7	10	.70	0
00803	1E-4A-2-21	7	10	.70	1
00804	1E-4A-2-35	7	10	.70	0
00805	1E-4A-2-32	7	10	.70	2
00806	1E-4A-2-28	7	10	.70	5
00807	1E-4A-2-53	7	10	.70	0
00808	1E-4A-2-29	7	10	.70	14
00809	1E-4A-2-30	7	10	.70	0
00810	1E-4A-2-51	7	10	.70	0
		WEAPON SYSTEM: MINUTEMAN III			
		(SOURCE: 9)			
00901	21M-LGM30G-1-13	4	1	4	67
00902	21M-LGM30G-2-7-2	4	1	4	42
00903	21M-LGM30G-2-10-1	4	1	4	43
00904	21M-LGM30G-2-11-1	4	1	4	37
00905	21M-LGM30G-2-12-3	5	1	5	25
00906	21M-LGM30G-2-16-2	5	1	5	20

CONTROL NUMBER	TECHNICAL ORDER	NO. PEOPLE VV	NO. OF T.O.s	VV/T.O.	AFTO 22s
00907	21M-LGM30G-2-28-1	5	1	5	26
00908	31R3-4-25-2	4	1	4	8
00909	31S8-26SW5-2-1	4	1	4	1
00910	11N-RS12A-2-1	4	1	4	24

SMALL SYSTEMS

WEAPON SYSTEM: TRACAL

(SOURCE: 22)

01001	31R4-2G-192	12	3	4	3
01002	31R4-2GRN30-2	12	3	4	1
01003	31R4-2GRN31-2	12	3	4	2
01004	31R4-2G-182	7	1	7	1
01005	31R4-2GRN31-26WC-1	6	1	6	1

WEAPON SYSTEM: GATES

(SOURCE: 17)

01101	31M1-2FMQ7-1	5	6	.83	2
01102	31M1-2FMQ7-1	5	6	.83	1
01103	31M1-2FMQ-6WC-1	5	6	.83	1
01104	31M3-4-5-1	5	6	.83	2
01105	31M3-4-5-1-6WC-1	5	6	.83	1
01106	31M3-4-6-6WC-1	5	6	.83	1

WEAPON SYSTEM: UH-1

(SOURCE: 35)

01201	1H-1(U)-2-1A	2	1	2	4
01202	1H-1(U)-2-1B	2	1	2	13

CONTROL NUMBER	TECHNICAL ORDER	NO. PEOPLE VV	NO. OF T.O.s	VV/T.O.	AFTO 22s
01203	1H-1(U)-2-1C	2	1	2	12
01204	1H-1(U)-2-1D	2	1	2	26
01205	1H-1(U)-2-1E	2	1	2	62
		WEAPON SYSTEM: AFSATCOM			
		(SOURCE: 27)			
01301	12R2-2A-412	15	6	2.5	2
010302	12R2-2U-142	15	6	2.5	1
01303	33D7-47-62-1	15	6	2.5	1
01304	33D7-6-185-1	15	6	2.5	1
01305	31R2-4-479-1	15	6	2.5	0
01306	31S5-4-788-2	15	6	2.5	0
		WEAPON SYSTEM: 427M			
		(SOURCE: 10)			
01401	31S5-2FSC80-1	2	1	2	0
01402	31S5-4-551-1	2	5	4	2
01403	31S5-4-551-3-1	2	5	4	3
01404	31S5-4-551-4	2	5	4	1
01405	31S5-4-551-3-2	2	5	4	0
01406	31S5-4-551-6WC-1	2	5	4	2
01407	31S5-2FYQ69-1	3	3	1	13
01408	31S5-2FYQ69-4	3	3	1	7
01409	31S5-2FYQ69-6WC-1	3	3	1	0
01410	31S5-4-345-11-1	3	6	.50	6
01411	31S5-4-345-11-3	3	6	.50	3

CONTROL NUMBER	TECHNICAL ORDER	NO. PEOPLE VV	NO. OF T.O.s	VV/T.O.	AFTO 22s
01412	31S5-4-345-11-2	3	6	.50	1
01413	31S5-4-345-11-13	3	6	.50	4
01414	31S5-4-345-11-14	3	6	.50	10
01415	31S5-4-345-16WC-1	3	6	.50	0
01416	31S5-4-547-1	2	5	.40	0
01417	31S5-4-547-3-1	2	5	.4	9
01418	31S5-4-547-4	2	5	.4	0
01419	31S5-4-547-3-2	2	5	.4	0
01420	31S5-4-547-6WC-1	2	5	.4	0
01421	31S5-4-373-1	3	4	.75	13
01422	31S5-4-373-3	3	4	.75	3
01423	31S5-4-373-4	3	4	.75	1
01424	31S5-4-373-6WC-1	3	4	.75	0

WEAPON SYSTEM: DSP

(SOURCE: 25)

01501	31S1-2GKC1-1	9	10	.91	4
01502	31S1-2GKC1-3	9	10	.91	0
01503	31S1-2GKC1-4	9	10	.91	0
01504	31S1-2GKC1-6	9	10	.91	2
01505	31S1-2GKC1-101	9	10	.91	0
01506	31S1-2GKC1-104	9	10	.91	1
01507	31S1-2GKC1-121	9	10	.91	8
01508	31S1-2GKC1-123	9	10	.91	2

CONTROL NUMBER	TECHNICAL ORDER	NO. PEOPLE VV	NO. OF T.O.s	VV/T.O.	AFTO 22s
01509	S31S1-2GKC1-124	9	10	.91	3
01510	S31S1-2GKC1-126	9	10	.91	0

WEAPON SYSTEM: AGM65

(SOURCE: 11)

01601	21M-AGM65A-2-1	15	4	3.85	25
01602	33D9-45-29-1	15	4	3.85	10
01603	33D9-61-37-1	15	4	3.85	9
01604	33D5-60-9-2	15	4	3.85	14

WEAPON SYSTEM: BISS

(SOURCE: 24)

01701	31S9-4-41-6WC-1	11	10	1.11	7
01702	31S9-4-42-6WC-1	11	10	1.11	6
01703	31S9-4-43-6WC-1	11	10	1.11	6
01704	31S9-4-2G-181	11	10	1.11	7
01705	31S9-2T-151	11	10	1.11	1
01706	33D7-38-78-1	11	10	1.11	3
01707	31S9-2G-121	11	10	1.11	1
01708	31S9-2G-141	11	10	1.11	1
01709	31S9-2G-111	11	10	1.11	1
01710	31S9-2GSS29-7	11	10	1.11	3

WEAPON SYSTEM: PAVE PENNY

(SOURCE: 8)

01801	11F3-6-2-2	12	17	.71	8

CONTROL NUMBER	TECHNICAL ORDER	NO. PEOPLE VV	NO. OF T.O.s	VV/T.O.	AFTO 22s
01802	11F13-32-2-2	12	17	.71	3
01803	33D5-20-27-1	12	17	.71	4
01804	33D5-64-2-1	12	17	.71	3

WEAPON SYSTEM: PAVE SPIKE

(SOURCE: 8)

01901	11F1-ASQ153-2	6	1	6	84
01902	33DA85-22-1	6	1	6	2

WEAPON SYSTEM: AAD-5/ASQ154

(SOURCE: 18)

02001	12S10-2AAD5-2	12	6	2	15
02002	33D10-10-10-1	12	6	2	3
02003	10A10-7-2	12	4	3	0
02004	33D10-12-140-1	12	4	3	0

APPENDIX B

RESEARCH RAW DATA

LISTH CURFIT

05/16/80   19.10

```
3REM C U R F I T
100 DATA 25,10,9,14,7,6,6,7,1,3,1,1,1,3,2
101 DATA 1,20,0,1,0,0,15,3,0,0,84,2,0,0,0
102 DATA 2,12,13,4,15,5,2,1,22,0,0,0,0,12,11
103 DATA 1,1,10,4,24,28,7,8,3,4,3
105 DATA 42,13,1,1,4,2,1,1,6,3,1,3,1,2,1
110 DATA 1,2,1,1,2,1,1,4,13,12,26,62,2,1,1,1,0,0,0
111 DATA 2,3,1,0,2,13,7,0,6,3,1,4,10,0,0
112 DATA 9,0,0,0,13,3,1,0,4,0,0,2,0,1,8
113 DATA 2,3,0,3,0,1,0,2,5,0,14,0,0
114 DATA 15,21,9,6,21,0,6,9,0,0,0,0,15,15,6,36,21,0,0,24,12,18,67
115 DATA 42,43,37,25,20,26,8,1
200 DATA 3.85,3.85,3.85,3.85,1.11,1.11,1.11,1.11,1.11,1.11,1.11,1.11,1.11
201 DATA 1.11,1.66,1.66,1.66,3,0.8,0.8,0.8,2,2,3,3,6,6,9,2.66,2.66,2.66
202 DATA 1,1,1,1,1,1,2.27,2.27,0.66,0.66,0.66,2,2,2,2,2,9,0.704,0.704,7.1
203 DATA 2,0.71,0.71,0.71,0.71,0.91,0.91,0.91,0.91,0.91,0.91,0.91,0.91
204 DATA 0.91,0.91,0.91,4,4,4,7,6,0.83,0.83,0.83,0.83,0.83,0.83,2,2,2,2
205 DATA 2,2.5,2.5,2.5,2.5,2.5,2.5,2,0.4,0.4,0.4,0.4,0.4,1,1,1,0.5,0.5
206 DATA 0.5,0.5,0.5,0.5,0.4,0.4,0.4,0.4,0.4,0.75,0.75,0.75,0.75,0.91
207 DATA 0.91,0.91,0.91,0.91,0.91,0.91,0.91,0.91,0.91,0.7,0.7,0.7,0.7
208 DATA 0.7,0.7,0.7,0.7,0.7,0.7
209 DATA 1.52,1.52,3,3,0.75,3,1.52,1.52,0.66,0.66,0.66,3,3,3,3,0.75
210 DATA 0.75,0.75,0.75,1,1,1,4,4,4,4,5,5,5,4,4
```

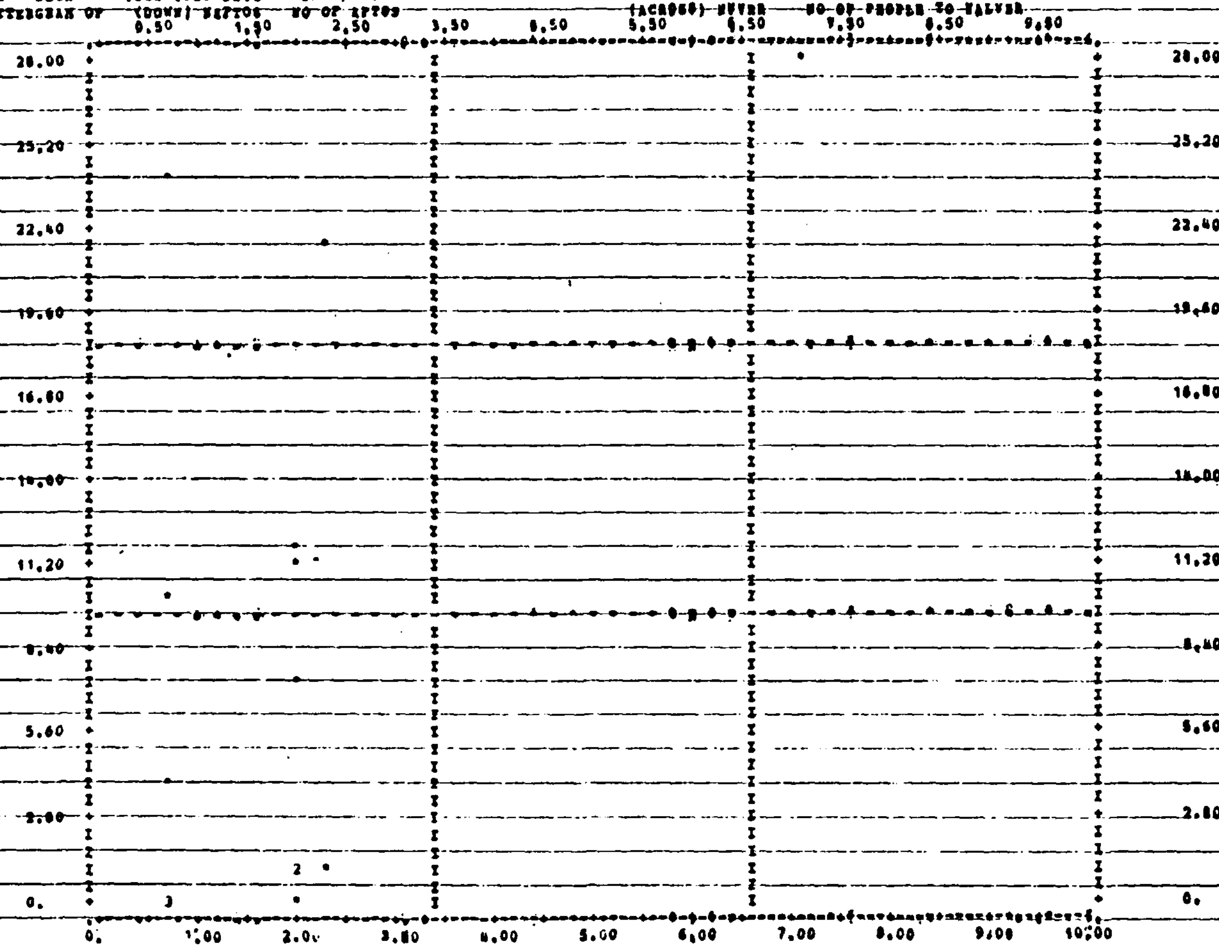
APPENDIX C

INDIVIDUAL SYSTEMS, A-10, C-5, 427M

A10 05/08/80 PAGE 4

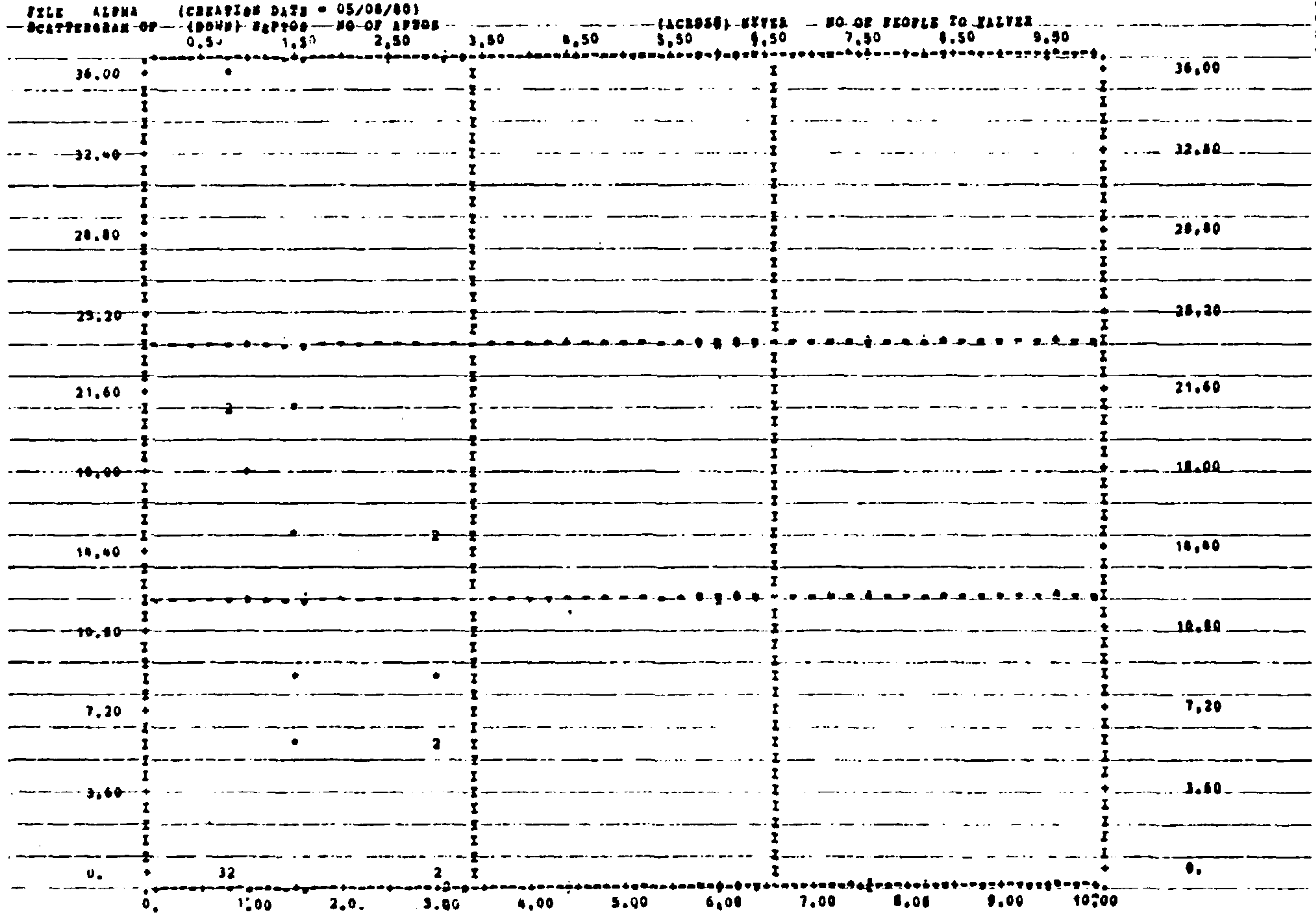
FILE BETA (CREATION DATE = 05/08/80)

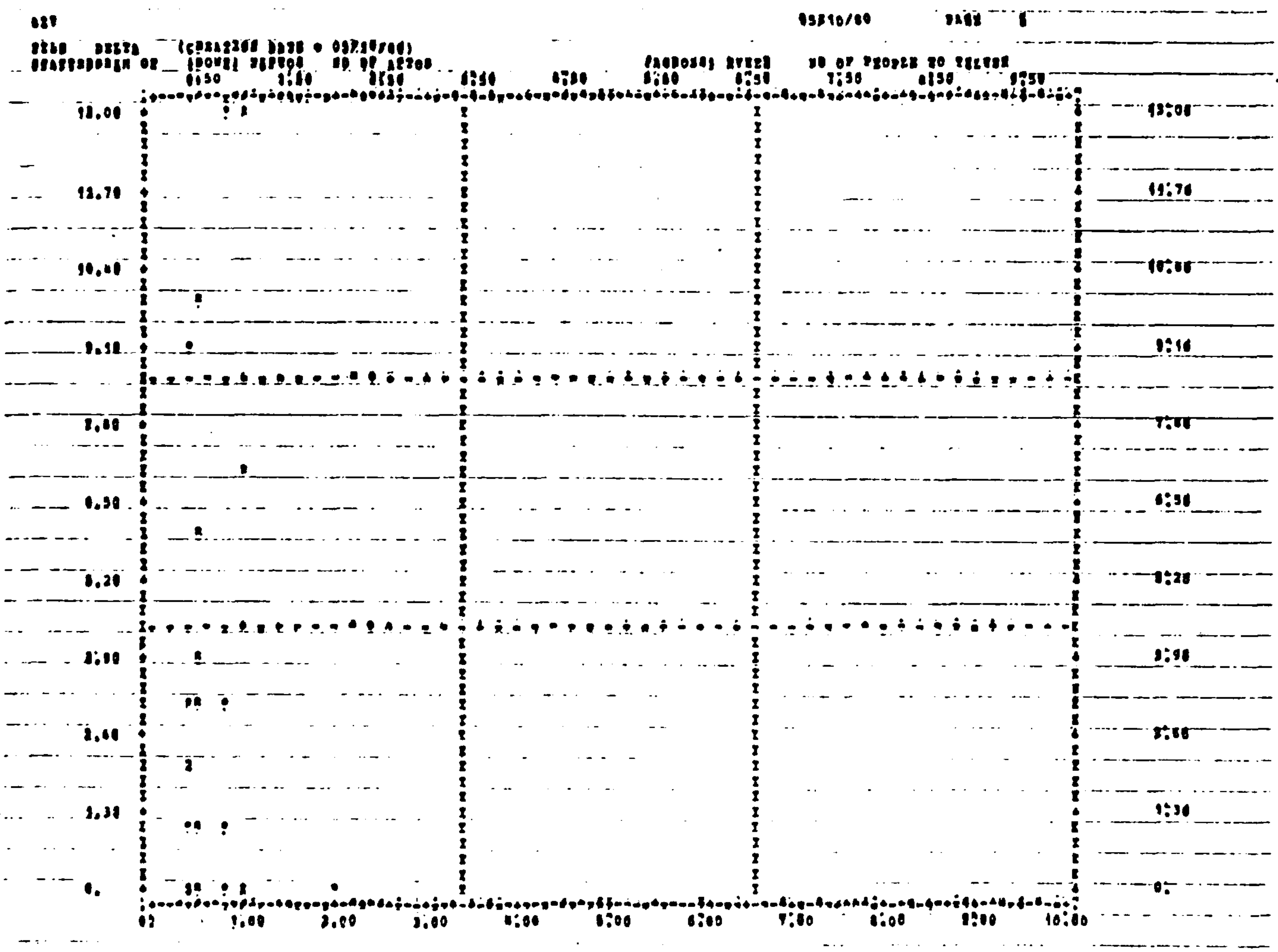
SCATTERGRAM OF (DOWN) SEPTOS NO OF SPTOS (ACROSS) NEVER NO OF PEOPLE TO TALKER



C5 05/08/80 PAGE 4

FILE ALPHA (CREATION DATE = 05/08/80)





APPENDIX D

COMPOSITE SYSTEMS (LARGE AND SMALL)

COMPOSITE WITH Y=AB**-X

FILE LCC (CREATION DATE = 05/19/80) COP2

CASE-N	VVER	AFTOS	PNVVER	PLVVER	PLAFTOS	MNVVER
1	4.	3.	5.	1.	1.	-5.
2	4.	1.	5.	1.	0.	-5.
3	4.	2.	5.	1.	0.	-5.
4	7.	1.	8.	1.	0.	-8.
5	6.	1.	7.	1.	0.	-7.
6	1.	2.	2.	0.	0.	-2.
7	1.	1.	2.	0.	0.	-2.
8	1.	1.	2.	0.	0.	-2.
9	1.	2.	2.	0.	0.	-2.
10	1.	1.	2.	0.	0.	-2.
11	1.	1.	2.	0.	0.	-2.
12	2.	4.	3.	0.	1.	-3.
13	2.	10.	3.	0.	1.	-3.
14	2.	12.	3.	0.	1.	-3.
15	2.	26.	3.	0.	1.	-3.
16	2.	62.	3.	0.	2.	-3.
17	3.	2.	4.	1.	0.	-4.
18	3.	1.	4.	1.	0.	-4.
19	3.	1.	4.	1.	0.	-4.
20	3.	1.	4.	1.	0.	-4.
21	3.	0.	4.	1.	0.	-4.
22	3.	0.	4.	1.	0.	-4.
23	1.	4.	2.	0.	1.	-2.
24	1.	0.	2.	0.	0.	-2.
25	1.	0.	2.	0.	0.	-2.
26	1.	2.	2.	0.	0.	-2.
27	1.	0.	2.	0.	1.	-2.
28	1.	1.	2.	0.	0.	-2.
29	1.	0.	2.	0.	1.	-2.
30	1.	2.	2.	0.	0.	-2.
31	1.	3.	2.	0.	1.	-2.
32	1.	0.	2.	0.	0.	-2.
33	2.	0.	3.	0.	0.	-3.
34	0.	1.	1.	0.	0.	-1.
35	0.	1.	1.	0.	1.	-1.
36	0.	1.	1.	0.	0.	-1.
37	0.	3.	1.	0.	1.	-1.
38	0.	2.	1.	0.	0.	-1.
39	1.	10.	2.	0.	1.	-2.
40	1.	7.	2.	1.	1.	-2.
41	1.	7.	2.	0.	0.	-2.
42	1.	5.	2.	1.	1.	-2.
43	1.	3.	2.	1.	1.	-2.
44	1.	1.	2.	0.	0.	-2.
45	1.	1.	2.	1.	1.	-2.
46	1.	10.	2.	0.	1.	-2.
47	1.	3.	2.	1.	1.	-2.

COMPOSITE WITH Y=AD**-X

FILE LOG (CREATION DATE = 05/19/80) COP2

CASE-N	VVER	AFTOS	PNVVER	PLVVER	PLAFTOS	MNVVER
48	0.	0.	1.	0.	0.	-1.
49	0.	9.	1.	0.	1.	-1.
50	0.	0.	1.	0.	0.	-1.
51	0.	0.	1.	0.	0.	-1.
52	0.	0.	1.	0.	0.	-1.
53	1.	13.	2.	0.	1.	-2.
54	1.	3.	2.	0.	1.	-2.
55	1.	1.	2.	0.	0.	-2.
56	1.	0.	2.	0.	0.	-2.
57	4.	25.	5.	1.	1.	-5.
58	4.	13.	5.	1.	1.	-5.
59	4.	7.	5.	1.	1.	-5.
60	4.	14.	5.	1.	1.	-5.
61	1.	7.	2.	0.	1.	-2.
62	1.	6.	2.	0.	1.	-2.
63	1.	6.	2.	0.	1.	-2.
64	1.	7.	2.	0.	1.	-2.
65	1.	1.	2.	0.	0.	-2.
66	1.	3.	2.	0.	1.	-2.
67	1.	1.	2.	1.	0.	-2.
68	1.	1.	2.	0.	2.	-2.
69	1.	1.	2.	0.	0.	-2.
70	1.	0.	2.	0.	1.	-2.
71	1.	0.	2.	0.	1.	-2.
72	1.	0.	2.	0.	1.	-2.
73	1.	4.	2.	0.	1.	-2.
74	1.	0.	2.	0.	1.	-2.
75	6.	84.	7.	1.	2.	-7.
76	6.	2.	7.	1.	0.	-7.
77	2.	15.	3.	0.	1.	-3.
78	2.	3.	3.	0.	1.	-3.
79	3.	7.	4.	1.	2.	-4.
80	3.	3.	4.	1.	3.	-4.
81	2.	17.	3.	0.	1.	-3.
82	2.	21.	3.	0.	1.	-3.
83	3.	9.	4.	1.	1.	-4.
84	3.	6.	4.	1.	1.	-4.
85	1.	21.	2.	0.	1.	-2.
86	3.	0.	4.	1.	1.	-4.
87	2.	6.	3.	0.	1.	-3.
88	2.	9.	3.	0.	1.	-3.
89	1.	0.	2.	0.	1.	-2.
90	1.	0.	2.	0.	1.	-2.
91	1.	0.	2.	0.	0.	-2.
92	3.	0.	4.	1.	0.	-4.
93	3.	15.	4.	1.	1.	-4.
94	3.	15.	4.	1.	1.	-4.

COMPOSITE WITH Y=AB**-X

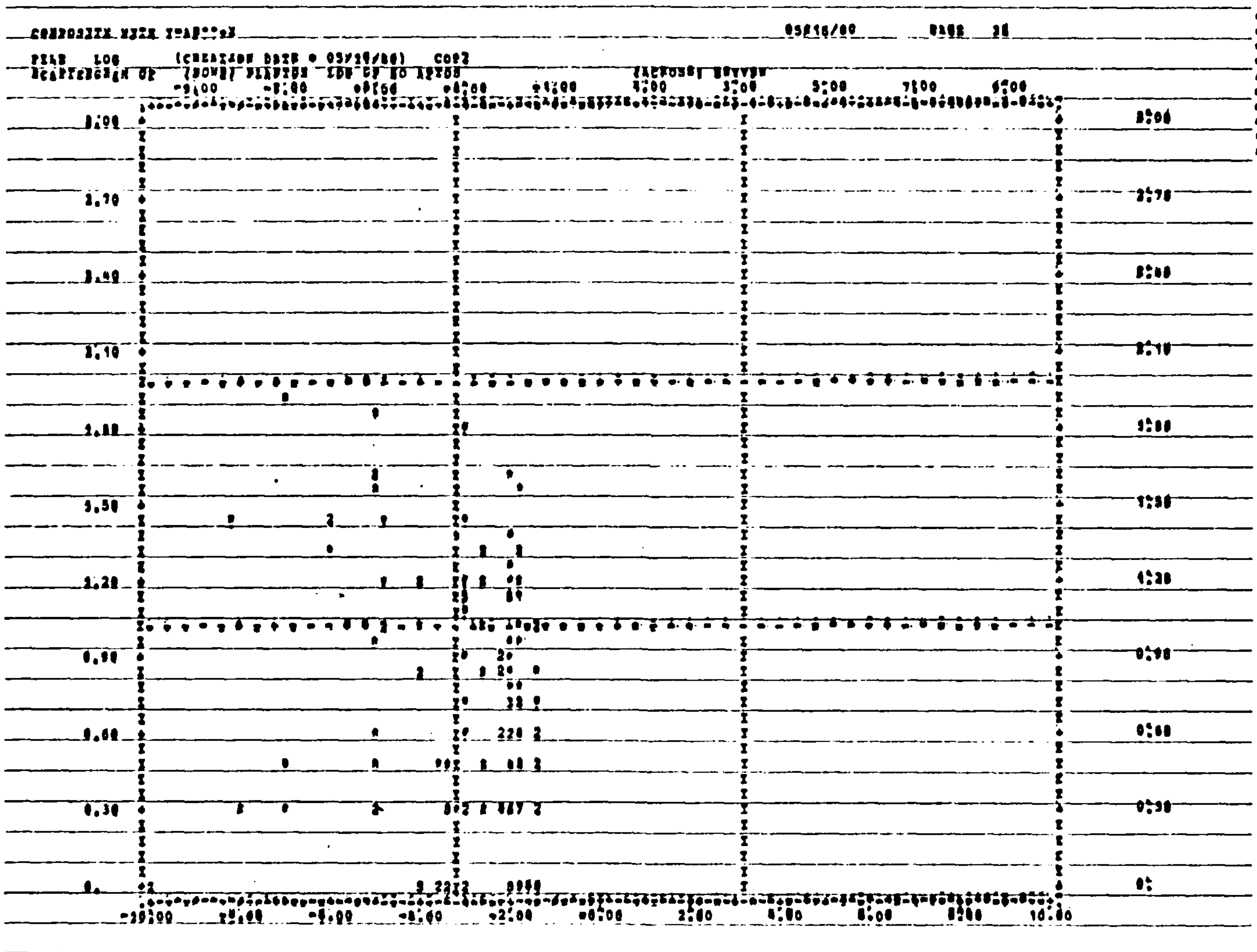
FILE LOG (CREATION DATE = 05/19/80) COP2

CASE-N	VVER	AFTOS	PNVVER	PLVVER	PLAFTOS	MNVVER
95	3.	6.	4.	1.	1.	-4.
96	1.	36.	2.	0.	2.	-2.
97	1.	21.	2.	0.	1.	-2.
98	1.	0.	2.	0.	0.	-2.
99	1.	0.	2.	0.	0.	-2.
100	1.	24.	2.	0.	1.	-2.
101	1.	12.	2.	0.	1.	-2.
102	1.	18.	2.	0.	1.	-2.
103	2.	1.	3.	1.	0.	-3.
104	2.	22.	3.	1.	1.	-3.
105	1.	0.	2.	0.	0.	-2.
106	1.	0.	2.	0.	0.	-2.
107	1.	0.	2.	0.	0.	-2.
108	2.	0.	3.	0.	0.	-3.
109	2.	12.	3.	0.	1.	-3.
110	2.	11.	3.	0.	1.	-3.
111	2.	1.	3.	0.	0.	-3.
112	2.	1.	3.	0.	0.	-3.
113	9.	0.	10.	1.	0.	-10.
114	1.	10.	2.	0.	1.	-2.
115	1.	4.	2.	0.	1.	-2.
116	7.	28.	8.	1.	1.	-8.
117	2.	7.	3.	0.	1.	-3.
118	9.	0.	10.	1.	0.	-10.
119	3.	0.	4.	1.	0.	-4.
120	3.	0.	4.	1.	0.	-4.
121	3.	2.	4.	1.	0.	-4.
122	1.	12.	2.	0.	1.	-2.
123	1.	10.	2.	0.	1.	-2.
124	1.	4.	2.	0.	1.	-2.
125	1.	15.	2.	0.	1.	-2.
126	1.	5.	2.	0.	1.	-2.
127	1.	2.	2.	0.	0.	-2.
128	2.	2.	3.	0.	0.	-3.
129	2.	1.	3.	0.	0.	-3.
130	2.	20.	3.	0.	1.	-3.
131	3.	0.	4.	1.	0.	-4.
132	1.	1.	2.	0.	0.	-2.
133	1.	0.	2.	0.	0.	-2.
134	1.	0.	2.	0.	0.	-2.
135	1.	42.	2.	0.	2.	-2.
136	1.	10.	2.	0.	1.	-2.
137	1.	1.	2.	0.	0.	-2.
138	1.	1.	2.	0.	0.	-2.
139	1.	4.	2.	0.	1.	-2.
140	1.	0.	2.	0.	0.	-2.
141	1.	1.	2.	0.	0.	-2.

COMPOSITE WITH Y=AB++-X

FILE LOG (CREATION DATE = 05/19/80) COP2

CASE-N	VVER	AFTOS	PNVVER	PLVVER	PLAFTOS	MNVVER
142	1.	1.	2.	0.	0.	-2.
143	1.	6.	2.	0.	1.	-2.
144	1.	3.	2.	0.	1.	-2.
145	1.	1.	2.	0.	0.	-2.
146	1.	0.	2.	0.	1.	-2.
147	1.	0.	2.	0.	0.	-2.
148	1.	1.	2.	0.	0.	-2.
149	1.	0.	2.	0.	0.	-2.
150	1.	2.	2.	0.	0.	-2.
151	1.	5.	2.	0.	1.	-2.
152	1.	0.	2.	0.	0.	-2.
153	1.	14.	2.	0.	1.	-2.
154	1.	0.	2.	0.	0.	-2.
155	1.	0.	2.	0.	0.	-2.
156	4.	67.	5.	1.	2.	-5.
157	4.	42.	5.	1.	2.	-5.
158	4.	40.	5.	1.	2.	-5.
159	4.	37.	5.	1.	2.	-5.
160	5.	25.	6.	1.	1.	-6.
161	5.	20.	6.	1.	1.	-6.
162	5.	26.	6.	1.	1.	-6.
163	4.	0.	5.	1.	1.	-5.
164	4.	1.	5.	1.	0.	-5.



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